

Module 211

Reservoir Flood Routing

**Engineering
Hydrology Training Series**

Module 211—Reservoir Flood Routing

National Employee Development Center
Natural Resources Conservation Service
United States Department of Agriculture
July 1999

Mention of trademarked or copyrighted items or equipment in this workbook does not constitute endorsement by the United States Department of Agriculture.

The United States Department of Agriculture (USDA) prohibits discrimination in its programs on the basis of race, color, national origin, sex, religion, age, disability, political beliefs, and marital or family status. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact the USDA Office of Communications at (202) 720-5881 (voice) or (202) 720-7808 (TDD).

To file a complaint, write the Secretary of Agriculture, U.S. Department of Agriculture, Washington, DC 20250, or call (202) 720-7327 (voice) or (202) 720-1127 (TDD). USDA is an equal employment opportunity employer.

Preface

This module consists of a study guide which provides a brief overview of reservoir flood routing.

Proceed through this module at your own pace. Be sure you completely understand each section before moving on. If you have questions or need help, please request assistance from your supervisor. If your supervisor cannot clear up your problems, he/she will contact the state-appointed resource person. The resource person is familiar with the material and should be able to answer any questions you may have.

Be sure to write out your answers to the included activities. This will help to reinforce your learning. After completing each activity, compare your answers with the included solution.

Acknowledgment

The design and development of this training module is the result of a concentrated effort by practicing engineers in the Natural Resources Conservation Service. The contributions from many technical and procedural reviews have helped make this module one that will provide needed knowledge of hydrology and hydraulics to NRCS employees.

Table of Contents

Preface	iii
Acknowledgment	iii
Introduction	1
Storage Indication Procedure	1
The Continuity Equation	2
Data Needed for Routing	7
Comparison of Common Routing Methods	12
Mass Curve Method	12
Graphical Methods	13
Storage Indication Method	13
Activity 1	20
Shortcut Reservoir Routing Methods	22
Activity 2	27
Activity 3	28
NNTC Shortcut Procedure	29
Emergency Spillway Routing Shortcut	29
NRCS Computer Programs for Reservoir Flood Routing	31
Test	33
Summary	36
Bibliography	37
Activity and Test Solutions	39
Certificate of Completion	49

Module Description

Overview

This module presents information NRCS engineers need to know about flood routing in order to design or understand the functioning of water control structures that temporarily impound flood water, such as dams, ponds, and other detention type structures. The module discusses the background and applications of different types of reservoir routing procedures with emphasis on the Storage Indication method. NRCS shortcut reservoir routing procedures are also discussed. Applicable NRCS computer programs that use the Storage Indication method and the shortcut procedures are identified and the routing procedure described. Information on how to use the programs is covered in the Computer Program Module series.

Objectives

Upon completion of this module, you will be able to

- Describe the Storage Indication method of reservoir routing.
- Identify shortcut reservoir routing methods.
- Identify computer programs the NRCS uses to route floods through structures and describe their general range of applicability.
- Perform at ASK Level 3 (Perform with supervision).

Prerequisite

Module 111—Reservoir Flood Routing

Duration

The participant should take as long as necessary to complete the module. Training time for the module is approximately three hours.

Eligibility

This module is intended for all NRCS personnel who use reservoir flood routing procedures.

Method of Completion

This module is self-paced, but the state should select a resource person to answer any questions that the participant's supervisor cannot handle.

Module 211—Reservoir Flood Routing

Introduction



In this module, you will be introduced to background information used to develop the Natural Resources Conservation Service reservoir routing procedures. You should have already completed Module 111—Reservoir Flood Routing. This module should give you a thorough understanding of reservoir flood routing, but you will need additional experience and supervision before doing them on your own.

Storage Indication Procedure

In Module 111, you learned that flood routing is the process of determining the timing and shape of a flood wave. In a reservoir, this is done by accounting for the storage available in the reservoir. In a channel, the flood wave is observed at successive points along a river. The storage and outflow are interdependent.

The Continuity Equation

The continuity equation used in reservoir routing observes the principle of conservation of mass. For a given time interval, the volume of inflow minus the volume of outflow equals the change in volume of storage. The equation is often written in one of the two forms given below.

$$\Delta t (\bar{I} - \bar{O}) = \Delta S \quad (1)$$

$$(\bar{I} - \bar{O}) = \Delta S / \Delta t \quad (2)$$

where

Δt = a time interval

\bar{I} = average rate of inflow during the time interval

\bar{O} = average rate of outflow during the time interval

ΔS = change in volume of storage during the time interval

The treatment of reservoir routing in this module is based on the assumption that the reservoir is level. This means that both the outflow and the storage depend only on the water level in the reservoir. This is valid in the majority of reservoirs designed by NRCS. It is not valid in a reservoir where the backwater effect is such that a significant percentage of the temporary storage occurs as wedge storage between the sloping backwater surface and a horizontal plane extending upstream from the water surface elevation at the dam.

In many applications, the flow and storage variables are expanded as shown below.

$$\bar{I} = (I_1 + I_2)/2 \quad (2a)$$

$$\bar{O} = (O_1 + O_2)/2$$

$$\Delta S = S_2 - S_1$$

$$\Delta t = t_2 - t_1$$

where

t_1 = time at the beginning of the interval

t_2 = time at the end of the interval

I_1 = inflow rate at t_1

I_2 = inflow rate at t_2

O_1 = outflow rate at t_1

O_2 = outflow rate at t_2

S_1 = storage volume at t_1

S_2 = storage volume at t_2

Figure 1 shows the general configuration for a reservoir. As inflow exceeds outflow, the storage increases. If the outflow is greater than the inflow, the storage decreases as long as the water level is higher than the crest of the outlet device.

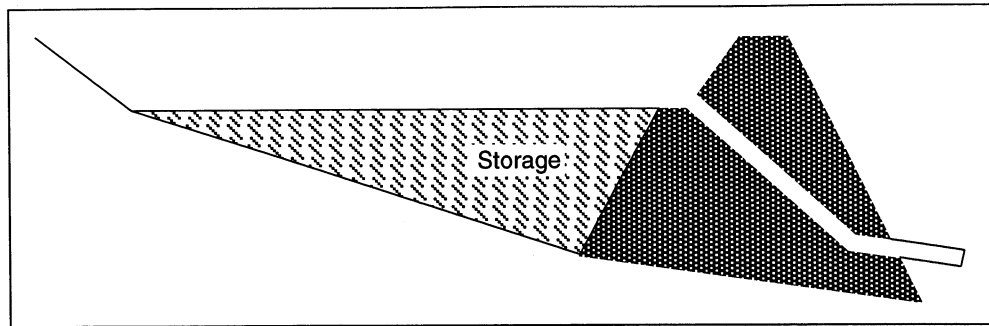


Figure 1. General Configuration of a Reservoir

Figure 2 shows another important principle of reservoir routing. The outflow is a maximum when the storage is a maximum. The outflow is dependent on the height of water above the crest of the outflow device, h . In the equations for orifice flow and weir flow given below, h is the only variable. So when h is a maximum, the discharge Q will be a maximum.

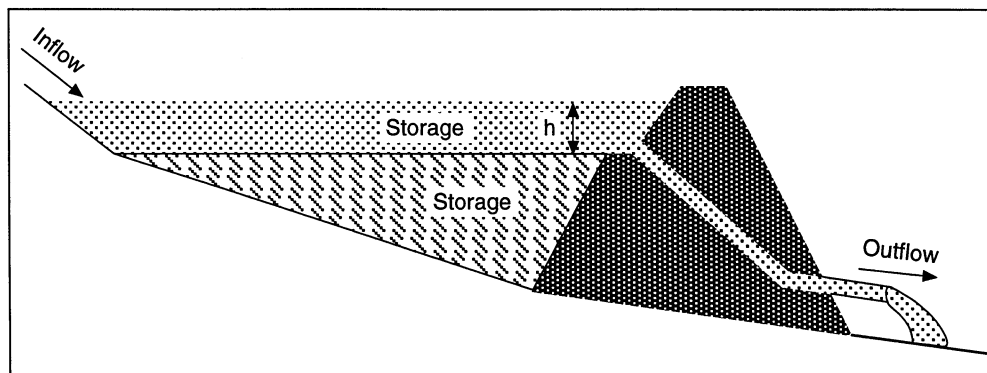


Figure 2. Reservoir Operations: Outflow is a maximum when Storage is a maximum as both are dependent on " h "

$$\text{Weir Flow: } Q = CLh^{3/2} \quad (3)$$

$$\text{Orifice Flow: } Q = CA(2gh)^{1/2} \quad (4)$$

where

Q = discharge, cfs

h = height of water above the weir crest, ft, OR distance from the center of the orifice to upstream free water surface

A = cross-sectional area, sq. ft.

C = coefficient (typically 3.1 in equation 3 and 0.6 in equation 4)

L = weir length, feet

g = gravitational constant = 32.2 ft/sec²

Under average conditions, the reservoir water level will stay at or near the crest of the outflow device. This is because the inflow from rain tends to offset the losses by evaporation, infiltration, and seepage. It then follows that outflow begins as soon as inflow does. Inflow raises the reservoir level by a small amount, which causes h in equations three and four and in figure 3 to become slightly larger than zero. This produces an initial small outflow. It is relatively small as the inflow's magnitude is dampened by the storage reservoir's volume.

In times of heavy rainfall, the outlet may flow for a long period of time and the reservoir's level may be higher than normal for a long period. This is illustrated in figure 3 by the letter a. In time of drought, evaporation and infiltration may exceed inflow; the water level in the reservoir will then fall below the crest of the outlet device. This is illustrated in figure 3 by the letter b. The first rains that appear will then have to restore the permanent pool level to the crest of the outflow device before outflow will begin.

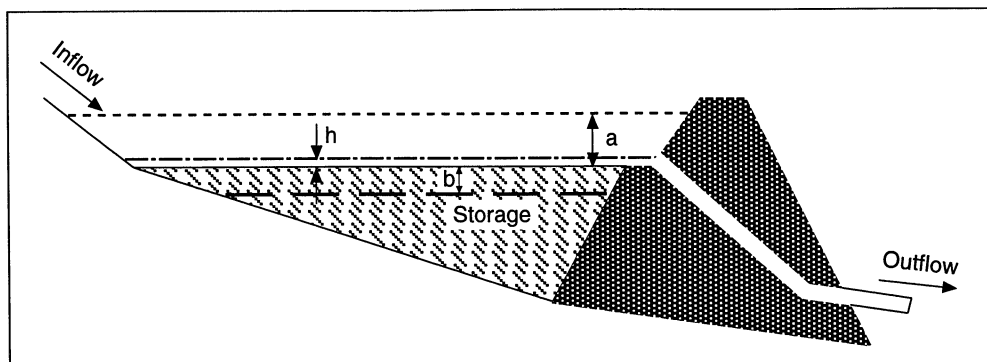


Figure 3. Reservoir Operations: (a) reservoir level after large rain; (b) reservoir level after prolonged drought; (h) reservoir level in typical case just after inflow begins so h is slightly more than zero.

Figure 4 illustrates the principle that the peak outflow falls on a point on the inflow hydrograph. This occurs when the inflow rate equals the rate at which the outflow device is releasing the water. The area $abdca$, or the difference between the inflow and outflow hydrographs, represents the volume stored. The volume of storage depleted is represented by area $dfged$, which equals area $abdca$.

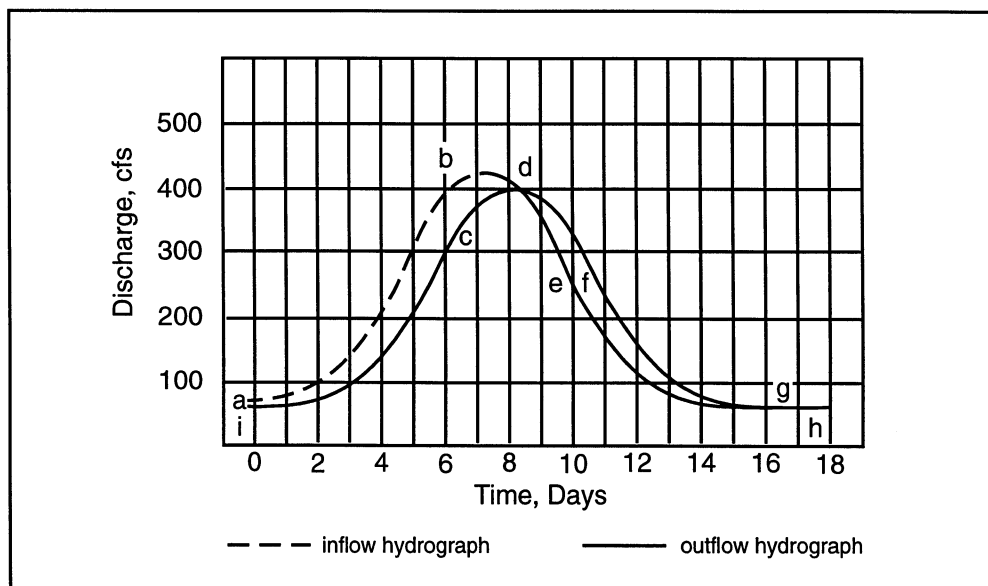


Figure 4. Peak outflow falls on a point on the inflow hydrograph. Hydrographs indicate volume stored and later released.

Data Needed for Routing

Numerous pieces of information are needed to complete a successful routing. The four listed here will be described in the following paragraphs.

- Stage-storage relationship
- Stage-discharge relationship
- Starting elevation (stage)
- Inflow hydrograph and baseflow

Stage-storage relationship

In order to relate inflow to storage, one must be able to relate the storage volume in the reservoir to elevation. This is depicted graphically or in a table. Figure 5 illustrates a stage-storage relationship. This may be estimated from maps or surveyed in the field. Stage may be expressed as it relates to a surveyed or assumed benchmark elevation or as it relates to a selected point, such as the bottom of the storage reservoir. Calculation of storage was discussed in module 111.

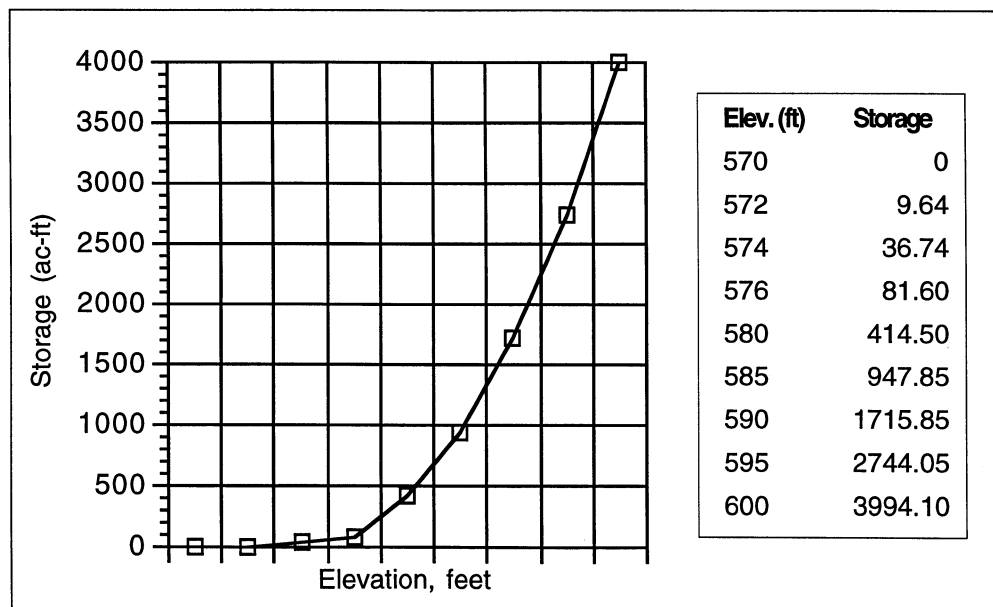


Figure 5. Elevation-Storage relationship for a reservoir

Stage-discharge relationship

This relationship depends on the type of outflow device in the reservoir. Formulas such as equations three and four are used to relate the elevation of the water surface to the discharge. The elevation of the outlet device is known or assumed. The head, h , is added to this elevation to obtain the elevation of the water surface. An example of a stage (or elevation)-discharge table is given in figure 6. The elevation-discharge relationship can be combined with the stage-storage relationship described above to relate storage to discharge. This is illustrated in figure seven. One can then apply the storage indication method to route a hydrograph through the reservoir.

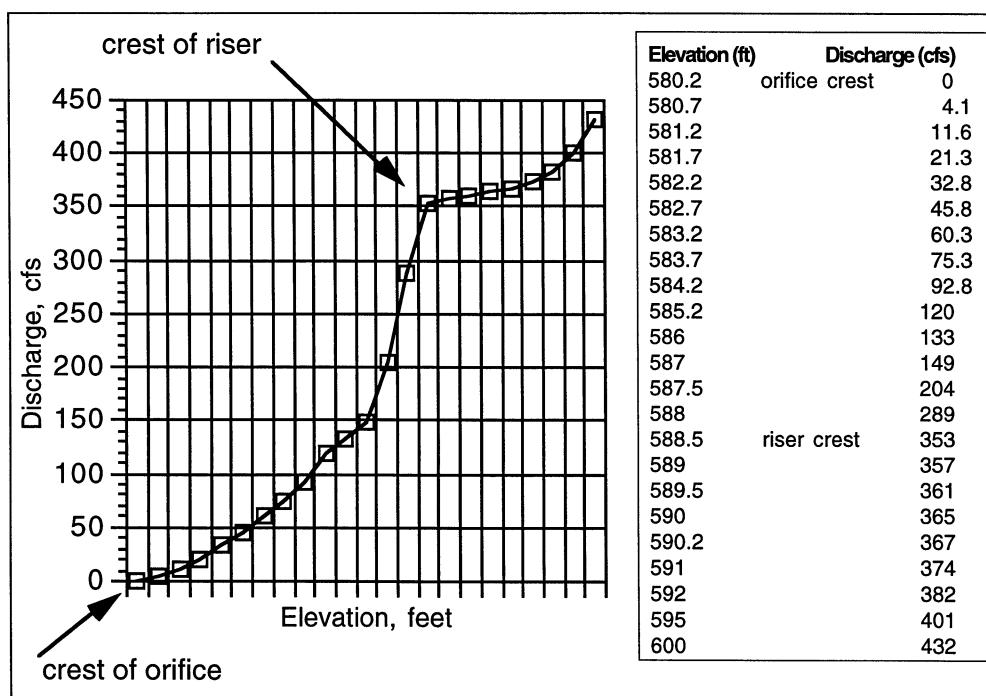


Figure 6. Elevation-discharge relationship for a reservoir with a two-stage principal spillway

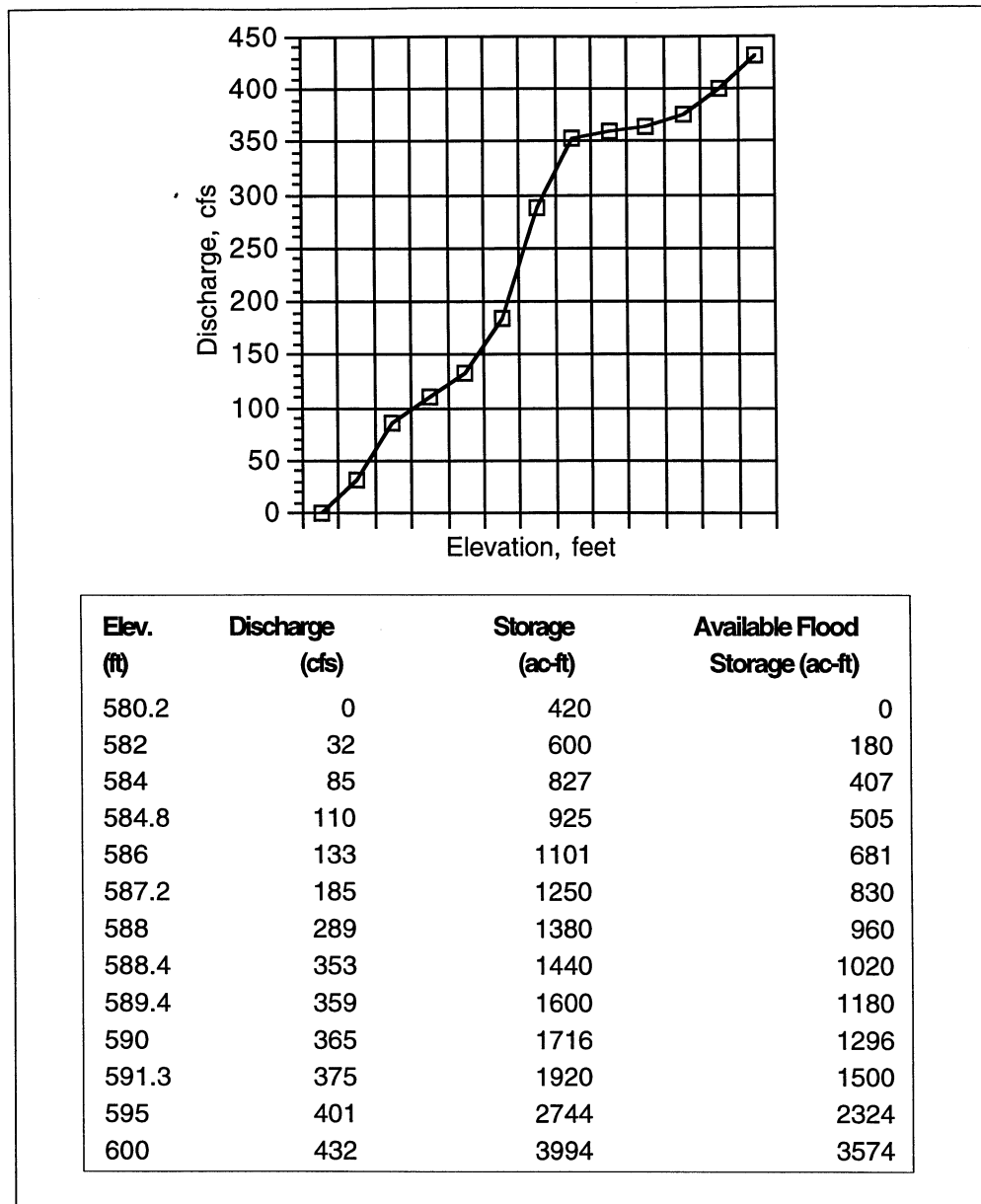


Figure 7. Storage-Discharge Relationship

Starting elevation

A starting elevation is assumed for the routing. If it has been extremely dry, the water surface level may be below the crest of the outlet device. In wet conditions, the reservoir may be above the crest of the outlet device so a small discharge is occurring. In average conditions, the water surface is likely to be at the crest of the outlet device.

Inflow hydrograph and baseflow

An inflow hydrograph must be known or assumed. This may be known from gage records. Several techniques for developing a synthetic hydrograph are described in literature. Module 207 also discusses hydrograph development. If there is a constant baseflow into the reservoir, this should be identified and considered in the routing.

Units

The units used in reservoir routing are commonly acre-feet, inches, cfs-hours and cfs-days. These terms are related to each other. One acre-foot of water is the volume of water that covers one acre of land with a depth of one foot. This unit is frequently used to describe the volume of a reservoir because the area is measured in acres and the depth in feet. "Inches" describes a volume of water that is one inch deep over the area of the watershed. "Cfs-hours" describes a volume of water that accumulates when a one cfs discharge flows for one hour. Similarly, "cfs-days" describes a volume of water that accumulates if a one cfs discharge flows for one day (24 hours). The relationship between these is shown below.

$$\frac{\text{ft}^3\text{-hour}}{\text{sec}} \times \frac{\text{day}}{24 \text{ hr}} = \frac{\text{ft}^3\text{-day}}{\text{sec}} \quad (5)$$

$$1 \text{ cfs-day} = 24 \text{ cfs-hours}$$

$$\frac{\text{ft}^3\text{-day}}{\text{sec}} \times \frac{3600 \text{ sec}}{\text{hour}} \times \frac{24 \text{ hrs}}{\text{day}} \times \frac{\text{acre}}{43,560 \text{ ft}^2} = \text{acre-feet} \quad (6)$$

$$1 \text{ cfs-day} = 1.98 \text{ acre-feet}$$

$$1 \text{ inch} \times \text{Drainage Area (acres)} \times \frac{1 \text{ foot}}{12 \text{ inches}} = \text{acre-feet} \quad (7)$$

Time Increment

The time increment is the interval at which the ordinates of a hydrograph used in the routing are represented. The time increment selected for the reservoir routing must be sufficiently short to capture the changes in the reservoir level and to define the hydrograph adequately, yet long enough to be practical and reasonable. The period should be short enough so that the hydrograph during the period approximates a straight line.

Comparison of Common Routing Methods

Mass Curve Method

The mass-curve method of reservoir routing is very versatile. It can be applied numerically or graphically. A mass flow curve is a plotting of accumulated volume of flow and time. At any point, that is, at any time, the slope of the mass flow curve, since it is a volume dimension divided by a time dimension, is equal to the rate of flow. The mass flow curve is the integral of the hydrograph since its ordinates measure accumulated volume at any time. The numerical routing operation is a trial and error procedure while the graphical approach is a direct solution. Each operation is a solution of equation eight below.

$$MI_2 - (MO_1 + \bar{O} \Delta t) = S_2 \quad (8)$$

where

MI_2 = mass inflow at time 2

MO_1 = mass outflow at time 1

\bar{O} = average discharge during the routing interval

Δt = routing interval = time 2 minus time 1

S_2 = storage at time 2

Graphical Methods

These methods basically involve a graphical integration of the mass curve. They are time-consuming as significant quantities of data must be plotted to complete the analysis, yet they are much quicker than numerically solving all the equations involved. Additional information and examples for this method are given in NEH 5, Chapter 8. This is reference two in the bibliography.

Storage Indication Method

Reservoir routing methods that can also be used for stream routing are generally discharge methods, not mass methods, because a discharge hydrograph is the desired output. This method uses discharge rates as both input and output. Two shortcomings of the method should be acknowledged.

- Outflow begins at the same time inflow begins so, presumably, the inflow at the head of the reservoir passes instantaneously through the reservoir regardless of its length. This is not serious if the time to peak on the inflow hydrograph is at least twice as long as the travel time through the reservoir.
- There is no rule for selecting the proper time increment. Page 17-22 of the August 1972 edition of NEH 4 deals with this concern and how it can be addressed. The reservoir routing in NRCS's TR-20 program is done by the storage-indication method. SITES also uses the storage-indication method. This method is examined further and a sample exercise provided.

Storage Indication Procedure

Figure 8 illustrates the derivation of the storage indication equation from the continuity equation. This provides the working form of equation ten used below in the storage indication procedure.

$$\bar{I} + S_1/\Delta t - O_{1/2} = S_2/\Delta t + O_{2/2} \quad (10)$$

$(\bar{I} - \bar{O}) = \Delta s/\Delta t \quad \text{(equation 2)}$ <p>Insert terms from equations 2a,</p> $\left[\bar{I} - \left(\frac{O_1 + O_2}{2}\right)\right] = \frac{S_2 - S_1}{\Delta t}$ $\bar{I} - \frac{O_1}{2} - \frac{O_2}{2} = \frac{S_2}{\Delta t} - \frac{S_1}{\Delta t}$ $\bar{I} + \frac{S_1}{\Delta t} - \frac{O_1}{2} = \frac{S_2}{\Delta t} + \frac{O_2}{2} \quad (10)$
--

Figure 8. Derivation of Storage-Indication Method Equation from the Continuity Equation

The following steps identify the procedure for reservoir routing. Examples in NEH 4, Chapter 17 begin on page 17-24 in the August 1972 edition.

Step 1

Identify the elevation-discharge relationship for the reservoir. This is illustrated in figure 6.

Step 2

Develop the elevation-storage curve for the structure. Figure 5 identifies this relationship. Sample calculations for an elevation-storage curve were shown in module 111.

Step 3

Develop and plot the inflow hydrograph. A principal spillway hydrograph is plotted in figure 9.

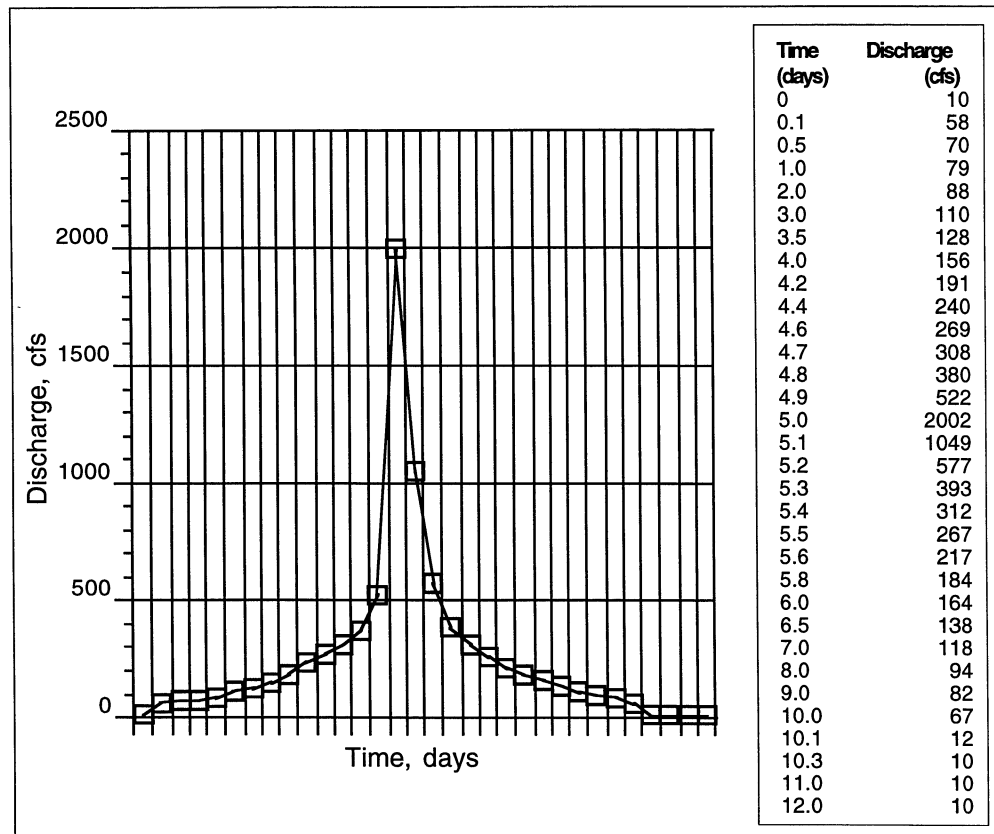


Figure 9. Inflow Hydrograph

Step 4

The routing interval must be selected. It may be advantageous to select two intervals—a longer one for small changes and a shorter one for larger changes.

Step 5

Prepare the working curves—one for each routing interval if more than one time unit is used. An example of this is given in table one. Column 2 in table one is read from figure 6, and likewise column 3 is read from figure 5 for the elevations selected in column 1. Column 4 is the values in column 2 divided by two. The values in columns 5 and 7 are those from column 3 divided by the respective time increments. Column 6 is the sum of columns 4 and 5, and likewise column 8 is the sum of columns 4 and 7.

(1) Elevation (ft)	(2) Discharge (O_2) (cfs)	(3) Storage (S_2) (cfs-days)	(4) $O_2/2$ (cfs)	(5) For $\Delta t = 0.5$ days $S_2/\Delta t$ (cfs)	(6) $S_2/\Delta t + O_2/2$ (cfs)	(7) For $\Delta t = 0.1$ days $S_2/\Delta t$ (cfs)	(8) $S_2/\Delta t + O_2/2$ (cfs)
580.2	0.0	0	0.00	0	0.00	0	0.00
581.2	11.6	49	5.80	98	103.80	490	495.80
582.2	32.8	98	16.40	196	212.40	980	996.40
583.2	60.3	159	30.15	318	348.15	1590	1620.15
584.6	104.0	236	52.00	472	524.00	2360	2412.00
586.0	133.0	333	66.50	666	732.50	3330	3396.50
587.0	149.0	407	74.50	814	888.50	4070	4144.50
587.5	204.0	444	102.00	888	980.00	4440	4542.00
588.0	289.0	482	144.50	964	1108.50	4820	4964.50
588.5	353.0	525	176.50	1050	1226.50	5250	5426.50
590.0	365.0	655	182.50	1310	1492.50	6550	6732.50
592.0	382.0	838	191.00	1676	1867.00	8380	8571.00
595.0	401.0	1174	200.50	2348	2548.50	11740	11940.50
	From Fig 6	From Fig 5	Col 2/2	Col 3/ Δt	Col 4+Col 5	Col 3/ Δt	Col 4+Col 7

Table 1. Preparation of working curves. Note conversion in Column 3 from acre-feet to cfs-days. Use equation 6.

Step 6

Prepare table 2—operations table with the headings and fill in columns 1 and 2 from the table in figure 9. These rates will be used for getting the \bar{I} values as it is difficult to select \bar{I} values accurately from some portions of the plotted hydrograph.

(1) Time (days)	(2) Inflow (cfs)	(3) \bar{I} (cfs)	(4) $S_2/\Delta t + O_2/2$ (cfs)	(5) $S_2/\Delta t$ (cfs)	(6) $O_2/2$ (cfs)	(7) Outflow (cfs)
0.0	0	0.0	0.0	0	0	0
0.5	70	35.0	35.0	33	2	4
1.0	79	74.5	105.5	99	6	12
1.5	84	81.5	175.0	162	13	26
2.0	88	86.0	235.0	216	19	38
2.5	99	93.5	291.0	267	24	48
3.0	110	104.5	347.0	317	30	60
3.5	128	119.0	406.0	369	37	74
4.0	156	142.0	474.0	428	46	92
4.5	245	200.5	582.0	526	56	112
			2684.0	2628	56	112
4.6	269	257.0	2829.0	2771	58	116
4.7	308	288.5	3001.0	2940	61	122
4.8	380	344.0	3223.0	3159	64	128
4.9	522	451.0	3546.0	3477	69	138
5.0	2002	1262.0	4670.0	4555	115	230
5.1	1049	1525.5	5966.0	5787	179	358
5.2	577	813.0	6421.0	6239	182	364
5.3	393	485.0	6542.0	6360	182	364
5.4	312	352.5	6530.0	6348	182	364
5.5	267	289.5	6456.0	6274	182	364
5.6	217	242.0	6334.0	6153	181	362
5.7	200	208.5	6180.0	6000	180	360
5.8	184	192.0	6012.0	5832	180	360
5.9	174	179.0	5831.0	5652	179	358
6.0	164	169.0	5642.0	5464	178	356
			1293.0	1115	178	356
6.5	138	151.0	1083.0	948	135	270
7.0	118	128.0	941.0	852	89	178
7.5	106	112.0	875.0	801	74	148
8.0	94	100.0	827.0	756	71	142
8.5	88	91.0	776.0	707	69	138
9.0	82	85.0	723.0	657	66	132
9.5	74	78.0	669.0	607	62	124
10.0	67	70.5	616.5	557	59	118
10.5	10	38.5	536.5	484	53	106
11.0	10	10.0	441.0	399	42	84
11.5	10	10.0	367.0	335	32	64
12.0	10	10.0	313.0	287	26	52
$\bar{I} + S_1\Delta t - O_1/2 = S_2\Delta t + O_2/2$						
$35 + 0 - 0 = 35$						

Table 2. Operations Table.

Step 7

Using the operations table, average the rates of inflow for each time unit and express it in the \bar{I} column. Add the inflow rate from the previous time unit to the rate in the present time increment and divide by two.

Step 8

Do the routing. This involves use of equation ten. $S_2/\Delta t$ and $O_2/2$ in columns 5 and 6 respectively become $S_1/\Delta t$ and $O_1/2$ in the next time increment when the equation is applied. The outflow in column 7 is twice the value in column 6 (Outflow = $2 \times O_2/2$). The term $S_2/\Delta t + O_2/2$ is broken into the two components ($S_2/\Delta t$ and $O_2/2$) using the appropriate columns from the working table developed in step five. The values are interpolated. Column 5 is subtracted from column four to obtain the value in column 6. Or, the value in column 6 could also be interpolated from the working table (such as using column 4 in table one).

Step 9

The maximum storage attained in the routing occurs when the inflow equals the outflow. This occurs at approximately time 5.3 hours in table 2. For this time, the value of $(S_2/\Delta t + O_2/2)$ is 6,542 cfs and $O_2 = 364$ cfs. Solving for S_2 and converting it to acre-feet, results in a maximum storage value of 1,259 acre-feet. (see computations at the bottom of table 2). Using this value with figure 5, the maximum storage value is reached when the reservoir is at elevation 587.3. The maximum outflow is 364 cfs, identifiable from column 7 in table 2.

Activity 1



At this time, complete activity one in the Study Guide to review the material just covered. After finishing the activity, compare your answers with the solution provided near the end of this module. When you are satisfied that you understand the material, continue with the Study Guide text.

Activity 1

Given



An engineer is interested in knowing the maximum storage that will be needed for a reservoir. The design inflow hydrograph is given as part of table four. Table three is a working table that identifies the elevation-discharge-storage relationships. The time interval has been selected. The routing is complete but several gaps in tables 3 and 4 are left to be filled in.

Find

The missing data entries in tables 3 and 4. Then determine the maximum storage volume needed for the design storm.

Solution

(1) Elevation (ft)	(2) Discharge (O_2) (cfs)	(3) Storage (S_2) (cfs-days)	(4) $O_2/2$ (cfs)	(5) For $\Delta t = 0.5$ days $S_2/\Delta t$ (cfs)	(6) $S_2/\Delta t + O_2/2$ (cfs)	(7) For $\Delta t = 0.1$ days $S_2/\Delta t$ (cfs)	(8) $S_2/\Delta t + O_2/2$ (cfs)
820	0	0	0	0	0	0	0
821	12	25	6	50	56	250	256
822	36	45	18	90	108		
823	66	70					
824	100	110					
825	136	156					
826	150	190	75	380	455	1900	1975
827	200	210	100	420	520	2100	2200
828	290	236		472		2360	
829	350	254		508		2540	
830	376	320	188	640	828	3200	3388

Table 3. Working Table for Activity 1.

(1) Time (days)	(2) Inflow (cfs)	(3) \bar{I} (cfs)	(4) $S_2/\Delta t + O_2/2$ (cfs)	(5) $S_2/\Delta t$ (cfs)	(6) $O_2/2$ (cfs)	(7) Outflow (cfs)
0.0	0	0.0	0.0	0	0	0
0.0	0	0.0	0.0	0	0.0	0
0.5	35	17.5	17.5	16	1.5	3
1.0	40	37.5	52.0	46	6.0	12
1.5	42	41.0	81.0	69	12.0	24
2.0	44	43.0	100.0	84	16.0	32
			433.0	417	16.0	32
2.1	50	47.0	448.0	431	17.0	34
2.2	75	62.5	476.5	458	18.5	37
2.3	130	102.5	542.0	520	22.0	44
2.4	240	185.0	683.0	653	30.0	
2.5	700	470.0				
2.6	820					
2.7	680					
2.8	510					
2.9	360		2797.0			
3.0	300	330.0	2773.0	2597	176.0	352
3.1	270	285.0	2706.0	2532	174.0	348
3.2	240	255.0	2613.0	2447	166.0	332
3.3	220	230.0	2511.0	2365	146.0	292
3.4	198	209.0	2428.0	2294	134.0	268
3.5	180	189.0				
4.0	160	170.0				
4.5	140	150.0	463.0	385	78.0	156
5.0	124	132.0	439.0	365	74.0	148
5.5	110	117.0	408.0	337	71.0	142
6.0	96	103.0	369.0	303	66.0	132
6.5	78	87.0	324.0	265	59.0	118
7.0	60	69.0	275.0	224	51.0	102

Table 4. Operations Table

Shortcut Reservoir Routing Methods

Various equations and charts have been developed for quickly estimating the required storage in a reservoir or the required capacity of a spillway. Usually these estimates are for preliminary studies of structures or projects. In most cases, the equations and charts are based on the results of actual routings so that using the equation or chart is, in effect, a form of routing.

Several methods are available as manual shortcuts for routing a principal spillway storm to determine the maximum amount of storage needed. They are discussed below.

Technical Release 33

Technical Release 33 presents a method to determine the minimum storage requirement for a floodwater retarding structure which has only a single-stage principal spillway, governed primarily by pipe flow. This procedure can only be used with Principle Spillway/Dam, TR-60, and assumes a 10-day hydrograph from TR-60. It saves plotting the mass curve. Eight charts estimate the storage needed in inches. The maximum time of concentration that can be used with this method is nine hours. In shallow reservoirs with gently sloping topography, the procedure may underestimate the required storage volume. This procedure has been used infrequently since the advent of microcomputers.

Technical Release 55

Technical Release 55, Chapter 6, offers the most recent development in the area of shortcut routing for reservoirs. Temporary storage was estimated initially using a statistical relationship that came to be known as the “beta equation”. The basic equation is given as equation 11.

$$V_s/V_r = C_0 + C_1(q_o/q_i) + C_2(q_o/q_i)^2 + C_3(q_o/q_i)^3 \quad (11)$$

where

V_s/V_r = ratio of storage volume (V_s) to runoff volume (V_r)

q_o/q_i = ratio of peak outflow discharge (q_o) to peak inflow discharge (q_i)

C_0, C_1, C_2, C_3 = coefficients (see table F-1 on page F-2 in June 1986 version of TR-55)

This was first developed many years ago as a single curve. In recent years, sufficient data has become available to develop the two curves shown in figure 10 for the different storm types used in NRCS.

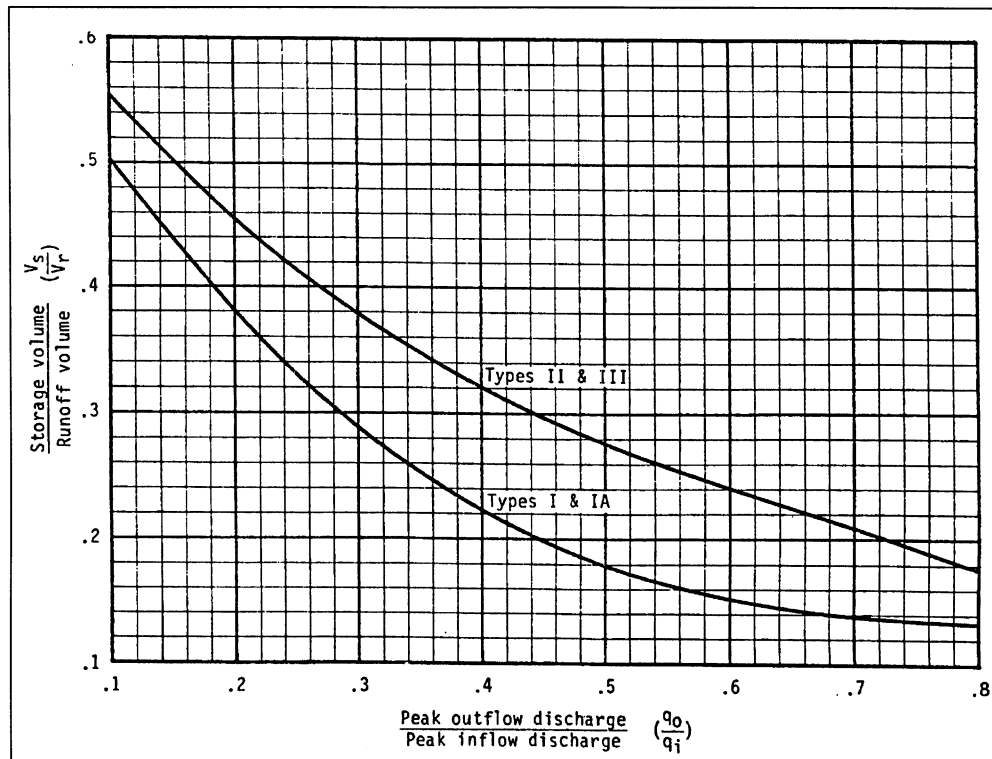


Figure 10. Approximate detention basin routing for rainfall types I, IA, II, and III.

Figure 11 identifies the general geographic locations that use a given storm type. Figures 10 and 11 are taken from Chapter 6 of TR-55.

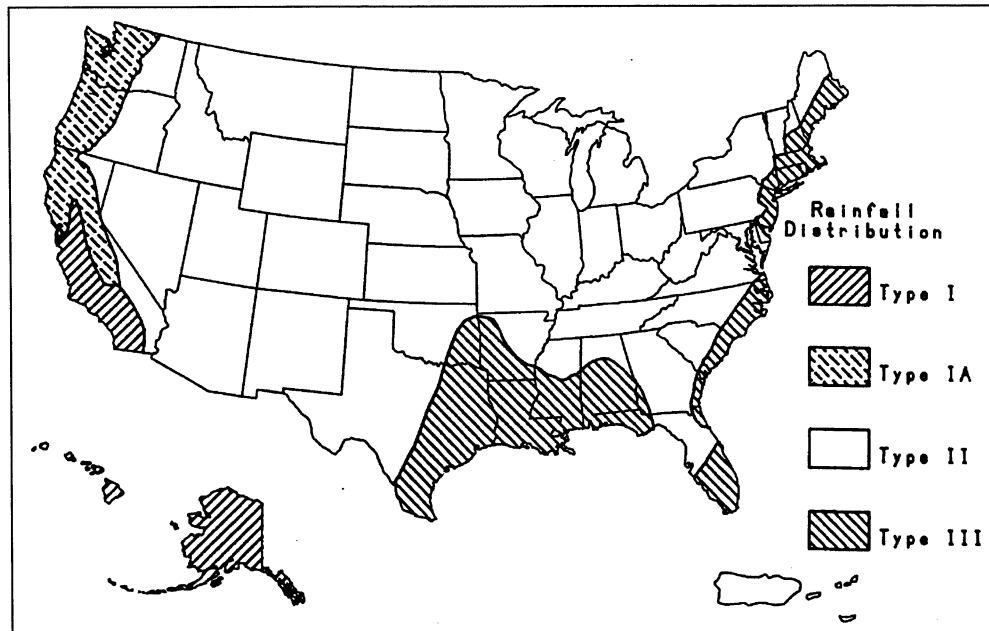


Figure 11. Approximate geographic boundaries for NRCS rainfall distributions.

The relationships in figure 10 were determined on the basis of single stage outflow devices. Some were controlled by pipe flow and others by weir flow. Verification runs were made using multiple stage outflow devices, and the variance was similar to that in the base data. The method can therefore be used for both single and multiple stage outlets. There are two constraints.

- Each stage requires a design storm and computation of the storage required.
- The discharge of the upper stage(s) includes the discharge of the lower stage(s).

Figure 10 can be used in two ways. If the storage volume is known, the peak outflow can be identified. If the peak outflow is known, the storage volume needed can be determined. This figure is biased to prevent undersizing outflow devices, but it may significantly overestimate the required storage capacity (by as much as 25 percent). The problems in activities 2 and 3 use this method as do the examples below.

Example A

A sediment basin is planned for a 25-acre site that has a peak inflow discharge of 24 cfs. The outlet structure has a peak capacity of seven cfs. The runoff volume from a four-inch rain is 2.04 inches. Assume a Type II storm distribution. What volume of storage is needed to handle this storm?

Solution

$$q_o/q_i = 7\text{cfs}/24\text{cfs} = 0.292$$

From Figure 10, using $q_o/q_i = .292$, $V_s/V_r = .386$

$$0.386 \times 2.04 \text{ inches} = 0.787 \text{ inches}$$

$$0.787 \text{ inches} \times 25 \text{ acres} \times 1 \text{ foot}/12 \text{ inches} = 1.64 \text{ acre-feet}$$

Example B

A sediment basin is planned for a 120-acre site that has a peak inflow discharge of 124 cfs. The runoff volume from a four-inch rain is 2.04 inches. Assume a Type II storm distribution. The site has natural storage capacity of five acre-feet. What does the capacity of the outlet structure need to be?

Solution

$$2.04 \text{ inches} \times 120 \text{ acres} \times 1 \text{ foot}/12 \text{ inches} = 20.4 \text{ acre-feet}$$

$$V_s/V_r = 5.0/20.4 = 0.245$$

Using Figure 10 with the Type II curve, $q_o/q_i = 0.59$

$$q_o = q_i \times 0.59 = 124 \text{ cfs} \times 0.59 = 73.2 \text{ cfs}$$

Activities 2 and 3



At this time, complete Activities 2 and 3 in the Study Guide to review the material just covered. After finishing the activities, compare your answers with the solutions provided. When you are satisfied that you understand the material, continue with the study guide text.

Activity 2

Given



A 153 acre watershed receives a five-inch rainfall. Since the watershed has a curve number of 75, 2.45 inches of rain are expected to run off (EFM, Exhibit 2-7). The maximum inflow to the reservoir is expected to be 190 cfs. (EFM, Chapter 2) The maximum discharge the outlet pipe can produce is 45 cfs.

Find

Using figure 10, determine the storage volume required.

Solution

Activity 3

Given



A 153 acre watershed receives a five-inch rainfall. Since the watershed has a curve number of 75, 2.45 inches of rain are expected to run off (EFM, Exhibit 2-7). The maximum inflow to the reservoir is expected to be 190 cfs. (EFM, Chapter 2) The maximum storage available at the site is 13.4 acre-feet.

Find

Using figure 10, determine the peak outflow discharge the pond must have.

Solution

NNTC Shortcut Procedure

The former Northeast NTC developed a shortcut procedure for the hydraulic design of two-stage risers in April 1983. The procedure relies heavily on the January 1975 version of TR-55, which has been replaced by the June 1986 version of TR-55. Eleven limitations are given for the procedure in the document, now known as Technical Note N3. The procedure is limited to geographic locations where Type II rainfall is used. The procedure is intended for class “a” structures with drainage areas less than 2000 acres. The lower stage of the riser is to be controlled by orifice flow and the high stage must be controlled by weir flow.

Emergency Spillway Routing Shortcut

Emergency spillway routing also has several shortcut methods. Two methods are described in NRCS Technical Releases 35 and 2. A third is illustrated in Figure 17-11 from NEH-4. All three of these methods are rarely used today because of the widespread availability of computers and software.

Technical Release 35 is a shortcut method for routing the emergency spillway and freeboard hydrographs which can be used when the principal spillway discharge is primarily pipe flow. It is based on a modification of Culp’s relationship for outflow hydrographs. The method utilizes dimensionless charts for the routing of freeboard and emergency spillway hydrographs through reservoirs and provides a quick means of arriving at the proper proportioning of water impounding structures.

Figure 17-11 from NEH-4 is included here as figure 12. It is similar to charts used with the beta equations (such as figure 10

included in this document). The noted difference is that figure 12 is for routing the combined flow for the principal and emergency spillways. The emergency spillway "surcharge" storage is included when computing the volume ratio. The curve shown here appears to be an enveloping curve valid for many types of structures and, as such, provides a conservative estimate, often useful in preliminary work.

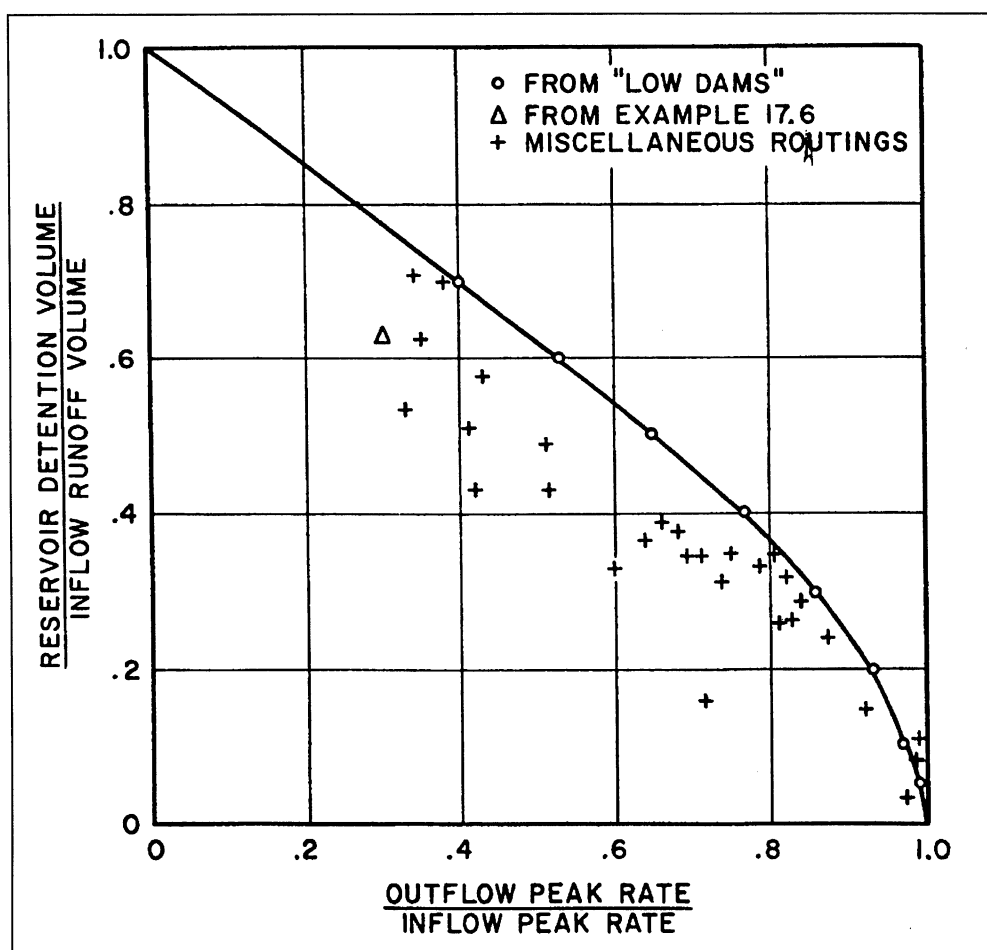


Figure 12. Typical shortcut method of reservoir flood routing.

NRCS Computer Programs for Reservoir Flood Routing

The Natural Resources Conservation Service has developed several computer programs to assist with the design of reservoirs, and the routing of storms through reservoirs. Four will be discussed briefly here with appropriate references.

TR-55 is a shortcut routing procedure.

A microcomputer program is available that facilitates computations and trying alternatives. This method approximates TR-20, in that a series of runs of TR-20 were done to develop the tables and charts contained in TR-55. The method is intended for “small watersheds” (less than 2000 acres) and is limited to applications where the time of concentration is less than two hours. TR-55 does not give the entire runoff hydrograph, nor does it give the entire runoff volume.

TR-55 is excellent for use with small watersheds, especially those changing from agricultural use to urban or industrial use. Hydrology Training Series module 251 is a study guide for using TR-55. It is recommended that you obtain and try this module if you plan to use TR-55.

The HYDRO-YARDAGE (Iowa Pond) Program

The HYDRO-YARDAGE (Iowa Pond) Program was developed in 1988 by Jack Langford. It is intended for the design of ponds falling under the 378 standard, but NOT for structures that require TR-60 criteria. It allows computation of earthwork yardages and cost estimates as well as the routing of the principal and emergency spillway storms. It is similar to SITES in some regards, but is more user-friendly, and offers input of survey data. It plots cross-sections and profiles on the screen and on paper.

TR-20

TR-20 is the original NRCS program for project formulation, or the planning of watersheds. It allows one to examine the effects of a watershed with and without improvement measures such as reservoirs, diversions, and channel improvements. TR-20 routes water as it moves from the top of a watershed to the point of interest. It is written in FORTRAN so has very specific requirements for data in fields. This has been aided in recent years by the development of an input program and a checking program. TR-20 takes some time to set up for an average watershed, but then can be a real time-saver for examining alternatives. The information requested as output from the program can be very detailed or general. Summary tables are provided to easily track the flow of water.

TR-20 uses the storage-indication method of reservoir routing. It handles large numbers of subwatersheds and channel cross-sections. It readily allows one to evaluate the effects of change in storage volume and outflow devices for one or more structures at any given time.

SITES

SITES is intended for the design of a flood retarding structure. It routes principal and emergency spillway storms through alternative designs and selects the outflow device size and the storage needed. It was developed for ponds and structures that must meet the criteria in TR-60 but is also satisfactory for ponds that must meet the criteria in standard 378.

Other programs may be available in your geographic area. Consult the State Conservation Engineer for other programs that should be included in this module for your state or area.

Test



Problem 1

An engineer wishes to determine the maximum storage elevation that will be reached in a reservoir. The outflow device is a four-foot long weir with a crest elevation of 580.0 feet. The storage table on the next page identifies the natural storage area that is available at the site. The inflow hydrograph is given in the first and second columns of the operations table for problem 1.

Find

The maximum storage elevation that will be reached in a reservoir by this storm using the storage-indication method of routing.

Solution

Problem 2



A 720 acre drainage area has a runoff curve number of 81. The 25-year precipitation event is 4.8 inches. Use a time of concentration of 2.4 hours with a Type II storm distribution. The natural storage available for a reservoir is 73.8 acre-feet. Using a shortcut routing technique, determine the peak outflow discharge needed to handle the storm.

Solution

Problem 3



A 532 acre drainage area has a runoff curve number of 73. The 10-year precipitation event is 6.2 inches. Use a time of concentration of 1.8 hours with a Type II storm distribution. The maximum outflow that is allowed by the local governing body is 250 cfs. Determine the volume of storage needed using a shortcut routing procedure.

Solution

Summary

Now that you have completed Module 211, you should be able to:

- Describe the storage indication method of routing.
- Identify several shortcut reservoir routing methods and provide justification for their use.
- Identify computer programs NRCS uses to flood route structures and describe their range of applicability.

You will need more practice and perhaps an additional training session before you become skilled in reservoir flood routing. The module on TR-55 is suggested as is examination of the Technical Releases mentioned.

Retain this study guide as a reference until you are satisfied that you have successfully mastered all the methods covered. It will provide an easy review at any time if you should encounter a problem.

If you have had problems understanding the module or if you would like to take additional, related modules, contact your supervisor.

When you are satisfied that you have completed this module, remove the Certification of Completion sheet (last page of the study guide), fill it out, and give it to your supervisor to submit, through channels, to your Training Officer.

Bibliography

USDA, Soil Conservation Service, *National Engineering Handbook*, Section 4, Hydrology, Chapter 17—Flood Routing, August 1972.

USDA, Soil Conservation Service, *National Engineering Handbook*, Section 5, Hydraulics, Chapter 8—Flood Routing Through Reservoirs.

USDA, Soil Conservation Service, *Engineering Field Manual*, Chapter 11—Ponds and Reservoirs, April 1980.

USDA, Soil Conservation Service, Technical Release No. 55, *Urban Hydrology for Small Watersheds*, Chapter 6—Storage Volume for Detention Basins, June 1986.

USDA, Soil Conservation Service, Technical Release No. 2, *Earth Spillways*, Tentative Issue, Oct. 1, 1956, 42 pages. Supplement A issued in May 1957, 10 pages.

USDA, Soil Conservation Service, Technical Release No. 35, *UD Method of Reservoir Flood Routing*, February 1967.

USDA, Soil Conservation Service, Technical Release No. 33, *Simplified Method for Determining Floodwater Retarding Storage*, 11 pages, April 1978.

Chow, Ven Te, *Handbook of Applied Hydrology*, McGraw Hill Book Company, 1964.

Schwab, Glenn, Richard Frevert, Talcott Edminster, Kenneth Barnes, *Soil and Water Conservation Engineering*, John Wiley and Sons, Inc., 1955, Revised 1966, 683 pages.

USDA Soil Conservation Service, Northeast NTC, Engineering Technical Note N3 (formerly #28), *Hydraulic Design of Two-Stage Risers By a Shortcut Method*, April 1983, 13 pages. Compiled by Donald E. Woodward.

Activity and Test Solutions

Activity 1

Given

An engineer is interested in knowing the maximum storage that will be needed for a reservoir. The design inflow hydrograph is given as part of table 4. Table 3 is a working table that identifies the elevation-discharge-storage relationships. The time interval has been selected. The routing is complete but several gaps in tables 3 and 4 are left to be filled in.

Find

The missing data entries in tables 3 and 4. Then determine the maximum storage volume needed for the design storm.

Solution

The maximum storage volume occurs when the inflow equals the outflow from the reservoir. This occurs at time 2.9 days when $(S_2/\Delta t + O_2/2)$ equals 2797 cfs.

$$\frac{S_2}{\Delta t} + \frac{O_2}{2} = 2797 \text{ cp} = \frac{S_2}{0.1 \text{ days}} + 177$$

$$S_2 = (2797 - 177)0.1 = 262 \text{ cfs} \cdot \text{days}$$

$$262 \text{ cfs} \cdot \text{days} \times \frac{1.98 \text{ ac} \cdot \text{ft}}{\text{cfs} \cdot \text{days}} = 519 \text{ ac} \cdot \text{ft}.$$

Maximum storage volume needed = 519 ac. ft.

(1) Elevation (ft)	(2) Discharge (O_2) (cfs)	(3) Storage (S_2) (cfs-days)	(4) $O_2/2$ (cfs)	(5) For $\Delta t = 0.5$ days $S_2/\Delta t$ (cfs)	(6) $S_2/\Delta t + O_2/2$ (cfs)	(7) For $\Delta t = 0.1$ days $S_2/\Delta t$ (cfs)	(8) $S_2/\Delta t + O_2/2$ (cfs)
820	0	0	0	0	0	0	0
821	12	25	6	50	56	250	256
822	36	45	18	90	1085	450	468
823	66	70	33	140	173	700	733
824	100	110	50	220	270	1100	1150
825	136	156	68	312	380	1560	1628
826	150	190	75	380	455	1900	1975
827	200	210	100	420	520	2100	2200
828	290	236	145	472	617	2360	2505
829	350	254	175	508	683	2540	2715
830	376	320	188	640	828	3200	3388

Table 3 Solution. Working Table for Activity 1.

Engineering Hydrology Training Series

(1) Time (days)	(2) Inflow (cfs)	(3) \bar{I} (cfs)	(4) $S_2/\Delta t + O_2/2$ (cfs)	(5) $S_2/\Delta t$ (cfs)	(6) $O_2/2$ (cfs)	(7) Outflow (cfs)
0.0	0	0.0	0.0	0	0	0
0.0	0	0.0	0.0	0	0.0	0
0.5	35	17.5	17.5	16	1.5	3
1.0	40	37.5	52.0	46	6.0	12
1.5	42	41.0	81.0	69	12.0	24
2.0	44	43.0	100.0	84	16.0	32
			433.0	417	16.0	32
2.1	50	47.0	448.0	431	17.0	34
2.2	75	62.5	476.5	458	18.5	37
2.3	130	102.5	542.0	520	22.0	44
2.4	240	185.0	683.0	653	30.0	60
2.5	700	470.0	1093.0	1045	48.0	96
2.6	820	760.0	1757.0	1686	71.0	142
2.7	680	750.0	2365.0	2240	125.0	250
2.8	510	595.0	2710.0	2536	174.0	348
2.9	360	435.0	2797.0	2620	177.0	354
3.0	300	330.0	2773.0	2597	176.0	352
3.1	270	285.0	2706.0	2532	174.0	348
3.2	240	255.0	2613.0	2447	166.0	332
3.3	220	230.0	2511.0	2365	146.0	292
3.4	198	209.0	2428.0	2294	134.0	268
3.5	180	189.0	2349.0	2227	122.0	244
			567.0	445	122.0	244
4.0	160	170.0	493.0	403	90.0	180
4.5	140	150.0	463.0	385	78.0	156
5.0	124	132.0	439.0	365	74.0	148
5.5	110	117.0	408.0	337	71.0	142
6.0	96	103.0	369.0	303	66.0	132
6.5	78	87.0	324.0	265	59.0	118
7.0	60	69.0	275.0	224	51.0	102

Table 4 Solution. Operations Table Solution

Activity 2

Given

A 153 acre watershed receives a five-inch rainfall. Since the watershed has a curve number of 75, 2.45 inches of rain are expected to run off (EFM, Exhibit 2-7). The maximum inflow to the reservoir is expected to be 190 cfs. (EFM, Chapter 2) The maximum discharge the outlet pipe can produce is 45 cfs.

Find

Using figure 10, determine the storage volume required.

Solution

$$(a) \quad V_r = Ad/12 = 153 \times 2.45/12 = 31.24 \text{ acre-feet}$$

$$Q_o/Q_i = 45/190 = 0.237$$

Using Figure 10 with $Q_o/Q_i = .237$, and a Type II storm distribution,

$$V_s/V_r = 0.422$$

$$V_s = (0.422)V_r = 0.422 \times 31.24 = 13.18 \text{ acre-feet}$$

Activity 3

Given

A 153 acre watershed receives a five-inch rainfall. Since the watershed has a curve number of 75, 2.45 inches of rain are expected to run off (EFM, Exhibit 2-7). The maximum inflow to the reservoir is expected to be 190 cfs. (EFM, Chapter 2) The maximum storage available at the site is 13.4 acre-feet.

Find

Using figure 10, determine the peak outflow discharge the pond must have.

Solution

$$V_r = 2.45 \text{ inches} \times 153 \text{ acres}/12 = 31.24 \text{ acre-feet}$$

$$V_s/V_r = 13.4/31.24 = 0.429$$

Using Figure 10, and a Type II storm distribution, Q_o/Q_i is 0.23. $Q_o = 0.23 \times Q_i = 0.23 \times 190 = 43.7 \text{ cfs}$.

Test

Problem 1

Determine the elevation-discharge relationship using the weir flow equation, $Q = CLH^{3/2}$ with $C = 3.2$ and $L=4$ ft.

Elevation	Discharge, cfs	
580	0.0	
581	12.8	Add this table of data to the working table for Problem 1
582	36.2	
583	66.5	
584	102.4	
585	143.1	
586	188.1	

See the storage table on the next page to see the computations of storage. These values were added to the working table also.

The working table was completed using the mathematical relationships as defined for each factor.

The inflow hydrograph points were averaged in the operations table and recorded in column 3 of the operations table. Using the storage-indication equation, columns 4 through 6 were completed as shown, by interpolating the values from the working table for problem 1. The values in column 7 are twice the values in column 6. This is the outflow hydrograph.

The maximum storage needed is at a point where the inflow equals the outflow, which is the same point where the storage function is maximized. In the operations table this is at about 4.4 hours.

$$S_2/t + O_2/2 = 681 \text{ cfs} = S_2/0.2 \text{ days} + 76 \text{ cfs}$$

$$S_2 = (681-76) \times 0.2 = 121 \text{ cfs-days}$$

$$S_2 = 121 \text{ cfs-days} \times 1.98 \text{ ac-ft/cfs-day} = 239.6 \text{ ac-ft}$$

Interpolating from the storage table, this volume correlates to an elevation of 585.24 feet.

Problem 2

The document used for the solution is TR-55. Using the graphical method in Chapter 4, for a curve number of 81 the I_a value is 0.469. Dividing 0.469/4.8 inches, $I_a/P = 0.0977$ or approximately 0.1.

$$720 \text{ acres} \times 1 \text{ sq.mi./640 acres} = 1.125 \text{ sq. mi. drainage area}$$

Using Exhibit 4-II (page 4-6) for a type II rainfall, with a time of concentration of 2.4 hours, the unit peak discharge is 200 csm/inch.

Using Table 2-1 on page 2-3, interpolate to obtain the runoff for 4.8 inches of rain and a curve number of 81.

	80	85	
4.5	2.46	2.91	from TR-55
5.0	2.89	3.37	from TR-55
4.8	2.72	3.19	interpolated from above lines

Further interpolation shows 2.81 is the runoff when RCN = 81

$$Q_i = 200 \text{ csm/inch} \times 2.81 \text{ inches} \times 1.125 \text{ sq. mi} = 632 \text{ cfs}$$

Runoff volume expected is 2.81 inches \times 720 acres \times 1 ft/12 inches = 168.6 acre feet. Therefore $V_s/V_r = 73.8/168.6 = 0.438$

Using Figure 6-1 on page 6-2, with $V_s/V_r = 0.438$, and a Type II storm distribution, $q_o/q_i = 0.223$. $Q_o = q_i \times 0.223 = 632 \text{ cfs} \times 0.223 = 141 \text{ cfs}$.

Problem 3

$$532 \text{ acres} \times 1 \text{ sq mi}/640 \text{ acres} = 0.83 \text{ sq. mi drainage area}$$

Using Table 2-1 in TR-55, interpolate for a precipitation of 6.2 inches and a runoff curve number of 73. The runoff is 3.26 inches.

Using Chapter 4 of TR-55 on the graphical method, determine the peak discharge. A curve number of 73 has an initial abstraction, I_a , of 0.740. Therefore $I_a/P = 0.74/6.2 = 0.12$. Use the curve for 0.1. Use Exhibit 4-II on page 4-6 with the time of concentration of 1.8 hours and find a q_u of 243 csm/inch. $Q_i = 243 \text{ csm/inch} \times 3.26 \text{ inches} \times 0.83 \text{ sq mi} = 657 \text{ cfs}$.

$$Q_o/Q_i = 250 \text{ cfs}/657 \text{ cfs} = 0.38$$

Using this ratio, determine V_s/V_r from Figure 6-1 on page 6-2 of TR-55.

$$V_s/V_r = 0.332$$

$$V_s = V_r \times 0.332 = 3.26 \text{ inches} \times 0.332 = 1.08 \text{ inches}$$

Convert this to acre feet: $1.08 \text{ inches} \times 532 \text{ acres} \times 1 \text{ ft}/12 \text{ inches} = 47.9 \text{ acre feet of storage is needed}$.

Hydrology Training Series Module 211—Reservoir Flood Routing

Certificate of Completion

This is to certify that

_____ has completed Hydrology Training Series
Module 211—Reservoir Flood Routing
on _____ and should be credited with three hours of training.

Signed _____ Supervisor/Trainer Participant

Completion of Hydrology Training Series
Module 211—Reservoir Flood Routing
is acknowledged and documented in the above-named employee's record.

Signed _____ Date _____
Training Officer

